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SUPERABRASIVE INDUSTRY REVIEW

Featuring Machining Advancements

THIS ISSUE

A Finer Point of View

High Volume Single-Crystal CVD Diamond for Industrial Applications

News & Notes

New Strategies for PcBN and Coatings in Hard Part Turning

IDA Member Companies

High Efficiency in Machining Carbon Fiber Composites & Metal Stacks for Aerospace Application

Calendar of Events

Membership Application

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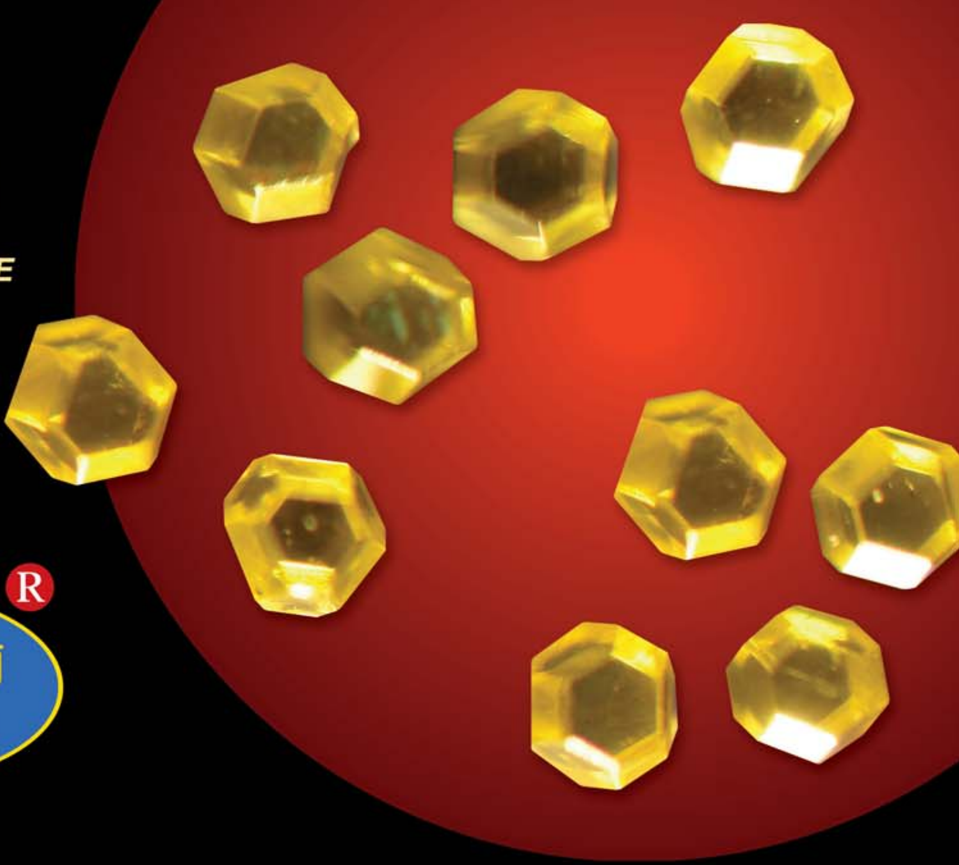

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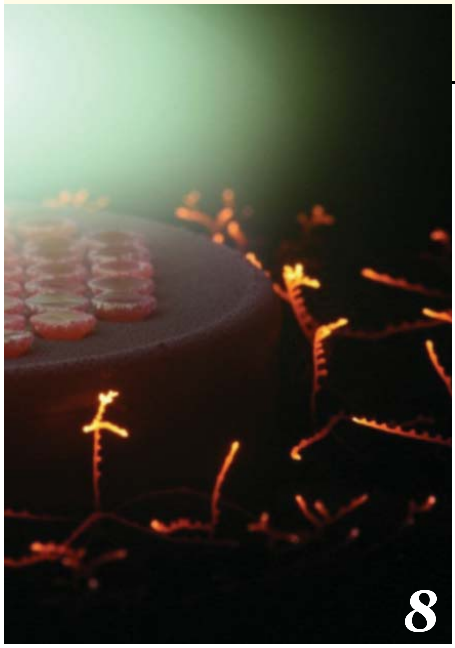

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COVER PHOTO

Photo Courtesy from World Steel Association of steel tube production at a Benteler Steel plant. Global steel production fell 1.5% in August, falling from 132.3 million metric tons in July to 130.35 million metric tons during August.

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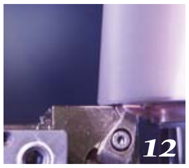
FINER POINTS is the longest running publication devoted exclusively to the understanding, selection and application of diamond, cubic boron nitride and related materials. It is edited for recipients who are involved in some way with these "superabrasives", either as providers of the materials, producers of products containing the materials or users of these products (e.g., grinding wheels, dressing tools, drill bits, saw blades, sawing wires, cutting tools, polishing compounds, CVD film products, etc.).



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A Finer Point of View…

The Industrial Diamond Association of America (IDA) has always been a major voice for the industry and a solid representative for its membership. As current President I have taken a step back just to see where we are and how we have progressed. There are two parts of a successful and enduring Association. First, I think any Association is only as good as the makeup and diversity of its membership and second, the dedication of the Board of Directors that step up to lead the organization ... Both of these elements have been the very heart of the IDA for almost 70 years! Our membership directory lists the notable presidents and companies that have served us so well throughout history and today, I would like to believe, we carry on that tradition. There is continuity and dedication over the past seven decades and the IDA has reinvented itself more than once over time. Gone are the days where most IDA member companies were strictly "diamond" businesses and tool makers using these diamond materials. Today we are very diverse and our companies range from toolmakers and machine tool builders to superabrasive suppliers and support companies offering testing equipment and raw materials. In the IDA you can find a company on the leading edge of CVD diamond and cBN research to unique metal materials used in superabrasive manufacturing.

The IDA has a proud history of providing research and development and application development of the products our companies provide to industry. Just in this Finer Points alone, you can see how major companies have invested in application development laboratories and inhouse testing facilities to keep our industry current and ahead of the demands of manufacturing operations.

Over the years the IDA membership has provided articles and research papers on numerous innovations and discoveries, that has never changed and today the IDA membership spearheads most of the major research done in the industry. Education has always been a strong point of the IDA and major conferences and seminars over the years have been benchmarks for the industry in this area. The IDA introduced a major education package two years ago at INTERTECH 2011 and next year the IDA Board of Directors will launch a new superabrasive education program that will address the very performance and characteristics of superabrasives along with the application nuances that only can come from the experts in the industry, the Members of the IDA!

PRESIDENT
Mike Mustin

I have addressed the diversity of our membership, but nothing comes full circle without strong leadership and the IDA has been fortunate to have many strong leaders as its Officers and Directors. Our Past President listing reads like a who's who of the diamond industry and I look at our Board of Directors and see a solid representation of all our businesses and we have a strong mix of established industry leaders and some fresh delegates. This elected management team gives us a valuable cross section of "been there, done that" with "let's try this, let's try that" for ideas and opinions. While we work hard to keep our IDA base structure and principals, we are advancing the industry and the IDA with new ideas in every area from social networks to electronic innovations and wondrous accomplishments in the digital world!

Today's IDA is involved in many projects too numerous to mention and we welcome any company to join us. Membership in the IDA is an outward sign you have been recognized as a trusted and honorable part of this industry. Today's Board of Directors is both dedicated and active ... Any company not a part of the IDA is missing having an organization that works for them 24 X 7 and 365 days a year!

Sincerely,

Mike Mustin
Industrial Diamond Association of America

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WWSA unveils a new state-of-the-art superabrasives materials characterization laboratory

WWSA continues our commitment to innovating new superabrasive products as well as providing industry leading technical support by adding a JEOL SEM with EDS and a Sonoscan D9600 to our materials characterization laboratory.

WWSA's new virtual grinding laboratory

WWSA unveils a new virtual grinding laboratory in September 2013 that will allow any customer in the world to interactively control a grinding experiment conducted at our Boynton Beach, Florida manufacturing facility. WWSA's new ANCA RX-7 5-axis grinding unit with dual coolant systems will allow our customers to develop and optimize the best superabrasive products to present to their customers.

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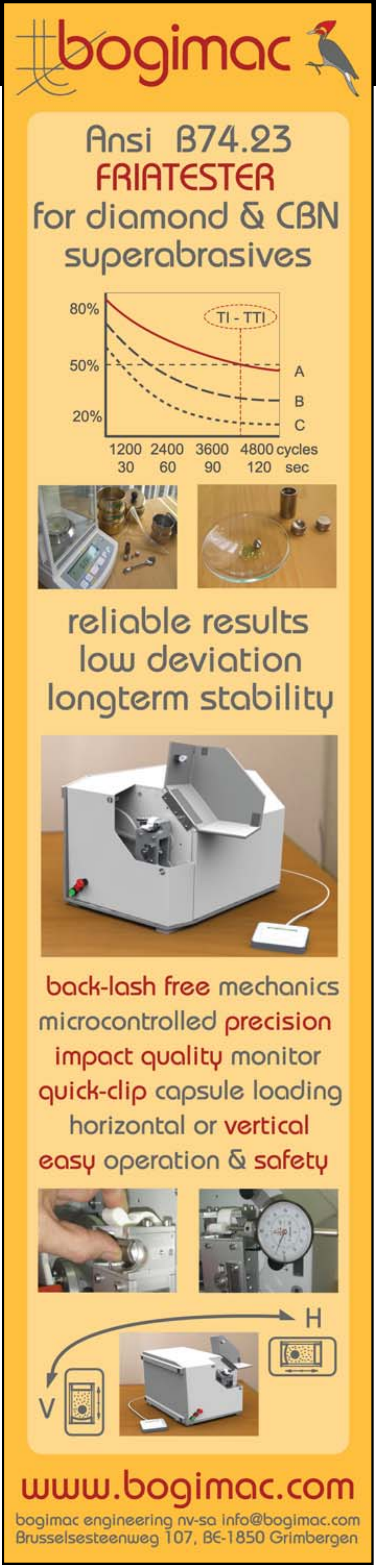
TERRY KANE, Editor

BEYOND REASON?

What is your reasonable expectation of accomplishment? I mean, when you are working around the house when do you really succeed at what you are doing and when are you happy. In a like manner, when you are selling a product to a new customer where does your level of satisfaction lie. Is it just making the sale or is it having the satisfaction of seeing an application running better than ever knowing you made it possible? Or could it be the constant reorder that reaffirms your success? There are a lot of areas where we have a chance to see a reasonable expectation of accomplishment. Of course there is our job, which is extremely important, but don't we also experience this in our personal life? A long successful marriage, an accomplished family where we see our children doing good in school or sports and maybe them having families, how far do we look to say we have achieved that level of accomplishment? Personally, I believe we never achieve total accomplishment. I think our lives are filled with individual moments of accomplishment and failure and then we move on to the next thing in our lives. There is an old adage that life should never be looked at as a destination, but as a trip and our life is that trip as we pass by each stage and event that make up our entire life. Those of us that have worked in industry over the years put tremendous stock in our accomplishments throughout our careers.

Just recently I was talking with an old colleague and he was very upset because he had just put over a year in working with an end user to develop a successful new application for the automotive industry using a specially developed new tool. My friend spent countless hours in the end user facility babysitting the operation and gauging each portion of the process to make sure everything was working properly. This was going to be a huge improvement over the previous process and my friend knew this would be a tremendous boon for his company since they had engineered and manufactured the tooling to such rigid standards. His efforts would be rewarded with a long term contract and the satisfaction of a highly productive and profitable operation for the end user ... Some of you have already guessed what happened next and I am sure many of you have experienced the same anger and frustration ... After the operation and tooling had been successfully qualified, the end user sought a low-cost supplier from overseas and in order to save a few dollars and started buying from that other company. My friend was devastated. All his hard work, knowledge and dedication had been bought off by a low cost supplier with no technological background or expertise. I remember something he said afterwards. "We maintain a high level of loyalty and dedication as a supplier, the end user has no reason to maintain the same integrity". This is a shame. I think the dedicated end user should hold themselves to the same standards and commitment as they expect from their suppliers.

Bottom line, that reasonable expectation of accomplishment would have been met if both parties had the same expectation and commitment ...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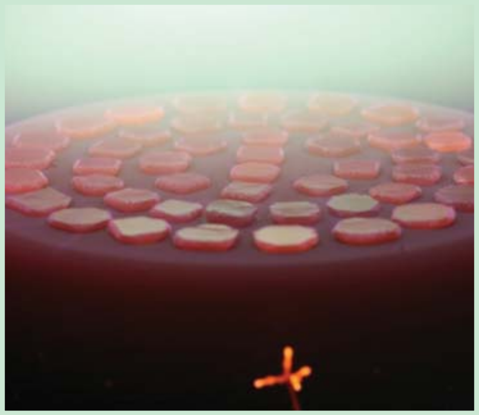
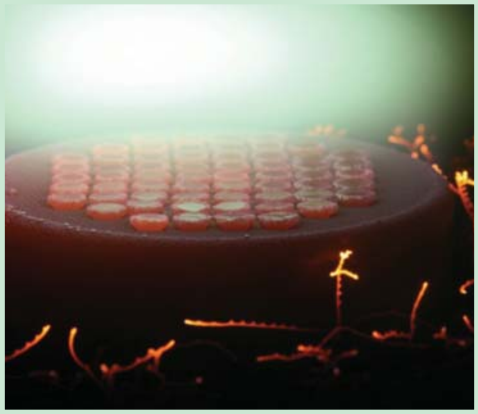


High Volume Single-Crystal CVD Diamond for Industrial Applications

MICHAEL W. MCMAHON, CHIEF EXECUTIVE OFFICER
Scio Diamond Technology Corporation

The demand for robust and precise parts of hard to machine alloys is steadily growing. The ability of mature fabrication industries to economically produce these parts requires access to unique and scarce super hard materials. These materials must be able to stand up to these new metals and alloys, be capable of maintaining high accuracy, and be cost effective. The availability of mass-produced Chemical Vapor Deposition (CVD) diamond can lead the path forward to address these issues for the development and fabrication of new products. Recently, a major supplier has been able to reduce a three-step process to a single step by taking advantage of the superior performance of diamond cutter blades. This achievement facilitated a multi-million dollar sales agreement with an international supplier of precision diamond tool products.

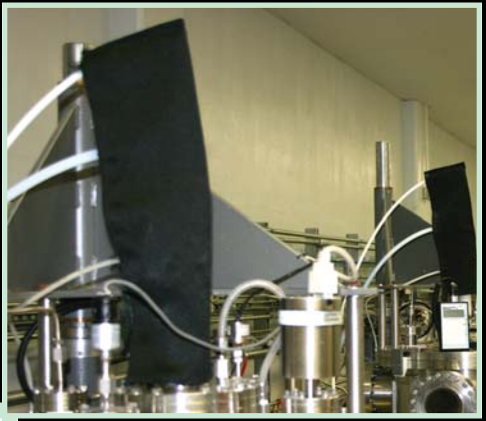


Single-Crystal CVD Diamond

To meet this diverse and increasing demand, CVD single-crystal diamond growth technology is rapidly expanding. The intrinsic advantage of CVD diamond is the ability to provide customizable enhancements. Growth recipes can be designed to control the amount of stress, hardness and color or transparency required for each application. This is not available with natural diamond and rarely available with HPHT material. The capability to provide stronger diamond materials, in mass-fabricated quantities with a consistency not achievable using natural or HPHT diamond opens up almost endless new possibilities for industrial applications.

There are several types of CVD reactors, but those that can customize their reactors to grow on a wide variety of substrate crystal sizes have unparalleled growth potential. The proprietary CVD reactor design developed by Scio Diamond has seen unprecedented expansion in its growth capability; scaling up from 16 crystals to 60 crystals per run as seen in figure 1 below. Utilizing larger seeds, from 4.5mm to 10mm, more than doubles the current product manufacturing. Additional scaling is planned using mosaic technology where two or more diamond seeds are joined together seamlessly. The ability to form very large seed crystals allows the current platform to produce significantly more product and become more and more cost effective.

The combination of increased seed size and the ability to grow continuously for hundreds of hours provides sufficient thickness, enabling multiple product pieces to be extracted from a single crystal. For example, going from 4mm x 4mm seeds to 7mm x 7mm seeds increases the output of industrial cutter blades by 60%. When you increase to roughly 10mm x 10mm seeds, production increases another 31%. All in all, a 110% increase using the same equipment and growth cycle. In addition to scaling seed crystals, higher production can be attained by utilizing larger CVD reactors. Going from a 3-inch platform to a 4-inch platform potentially increases yield by yet another 50%.



The Scio CVD process for growing diamond can now be scaled easily to provide sufficient quantities to satisfy market needs. However, as industrial diamond demand and supply has increased, the limited capacity for precise fabrication has emerged as one of the biggest impediments in the development of new products and in the ability to bring these products to market.

Single-Crystal CVD Diamond Fabrication

Just as single crystal CVD diamond growth is a challenge, the ability to then form and fabricate diamond into the shapes that various industries need can be a daunting task. Current fabricators have been limited to applications utilizing natural diamond or to polishing gemstones. The new availability of CVD diamond production and the additional applications it enables has made it clear that there is a growing need for skilled fabricators who are able to capitalize on its unique properties. The demand for the increasingly complex shapes required by the end users has forced CVD researchers to continually refine and reinvent fabrication technologies to meet these new demands.

Although industrial diamond uses have been around for decades, the support industry for fabricating and shaping diamond is not well developed. Some of this is a result of the historical control of the natural diamond market, which in turn strongly influenced the fabrication (polishing) sector. There is only one economical way to cut diamond and that is with lasers. The availability of the current commercial laser systems used in the fabrication of diamond is limited and the control software is growing more archaic, unable to fully address the commercial potentials now available. The use of shorter wavelength laser systems has shown improvements in reducing crystal damage compared to traditional IR laser wavelengths. Even with these improvements in technology, the fabrication of diamond is still somewhat of an art. To fully exploit the potential of CVD diamond we need to move away from art and into science and rapidly develop both higher capacity and new fabrication technologies.

In the past, the potential of diamond to solve many industrial problems has been limited by its cost, limited supply and uncontrolled quality. Today we now have the technology to consistently mass-produce single-crystal diamond of the highest quality at reasonable cost. This new capability opens the door to an almost limitless number of industrial and technological applications that take advantage of the unparalleled physical properties of diamond. Those that can combine diamond production capability with the equally important fabrication technology, through either vertical growth or strategic partnerships, will bring diamond to the industrial world in a way that has never been seen. Mass production of industrial diamond is becoming a reality and is happening today. ■

Beyond its application in fabrication and product manufacturing, single-crystal CVD diamond also has a long and rapidly growing list of industrial and technological applications where the diamond itself is the product. These include high-power high-frequency electronics, prisms for high-index waveguides, Quantum Electrodynamics, Raman spectroscopy, P/N junctions, electronics, radiation detectors for X-Rays, and femtosecond laser experiments. In addition, optical grade windows and prisms, high thermal conductivity heat sinks, diamond sheets for X-ray windows and CVD diamond as a basis for electronic Biosensors. Working with partners in the medical device field has shown the Ophthalmology and Plastic Surgery communities worldwide that the precision and durability available in CVD diamond scalpels exceeds anything available with current technology.

NEWS and notes

PRECISION EFORMING PARTNERS WITH GLENAMMER ENGINEERING; TO SUPPLY HIGH QUALITY, ENGINEERED, PRECISION WOVEN WIRE TEST SIEVES.

Precision Eforming, the global leader in the manufacturing of precision electroformed test sieves and metal mesh products is proud to announce their new partnership with Glenammer Engineering. Glenammer sieves are manufactured in Scotland, and are recognized throughout the world as being of the highest quality and the best value money can buy. As a stocking partner, Precision Eforming will offer the complete line of Glenammer products to include ASTM and ISO woven wire and perforated plate sieves in addition to our precision electroformed sieves and complete re-inspection and certification services'. For outstanding quality, delivery and customer service please contact sales@precisioneforming.com

ELEMENT SIX OPENS WORLD'S MOST ADVANCED SYNTHETIC DIAMOND INNOVATION CENTRE NEAR OXFORD, UK - LONDON

Element Six, a world leader in synthetic diamond supermaterials, opened the world's largest and most sophisticated synthetic diamond research and development facility. The $32m Global Innovation Centre (GIC), was officially opened by the (UK) Science Minister David Willetts MP, and Philippe Mellier, Chairman of Element Six. Employing over 110 scientists and technologists, the 54,000 Sq ft facility consolidates Element Six's global innovation teams into one integrated centre. The centre will develop a pipeline of innovative synthetic diamond and related supermaterial products for customers, in industries from oil and gas drilling to precision machining and electronics. Element Six has a 50 year, world-leading track record of applying the extreme properties of synthetic diamond within abrasive applications and a diverse range of advanced technologies. Facilities at the GIC include modelling and design, materials preparation, a High Pressure High Temperature synthesis press hall, Chemical Vapour Deposition reactor synthesis labs, post-synthesis processing (e.g. polishing, cutting, shaping), materials analysis/characterisation and end application testing. The result is a physical environment which fosters and enables open collaboration and partnership with customers' in support of their product development programs.

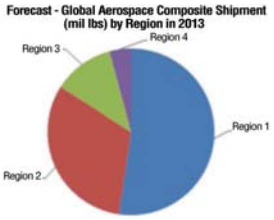
WITHIN THE LAST 12 MONTHS, FIVES HAS SIGNIFICANTLY STRENGTHENED ITS GLOBAL LEADERSHIP POSITION, THROUGH THREE STRATEGIC ACQUISITIONS. FIVES HAS COMPLETED THE ACQUISITION OF MAG AMERICAS.

With this strategic acquisition, Fives becomes one of the global leaders in high-precision machine tools, used to manufacture large complex equipment and high performance composite processing machines . Fives achieves the global leadership position, in part, as a result of the acquisition of the three worldrenowned MAG brands; Cincinnati, Giddings & Lewis and Forest-Liné. The acquisition of these brands is in line with Fives' ambition and strategy to further strengthen its position in high-growth sectors - such as the aerospace, renewable energy, mining and special equipment sectors. This acquisition strengthens Fives' global position. In fact, 1,000 employees of MAG Americas, based in the United States, France, Canada, China, Korea and Russia will join the 6500 Fives' employees in 30 countries. Fives provides process equipment, production lines and turnkey plants for the biggest global players in the aluminum, steel, glass, automotive, logistics, cement and energy sector in both developing and developed countries. For further information contact: Claire Mathieu claire.mathieu@fivesgroup.com

DIAMOND INNOVATIONS REACHES 2,000,000 CONSECUTIVE HOURS WITHOUT LTA *Worthington, Ohio*

The employees of one of the largest manufacturers in the Columbus, OH, area have reached a remarkable milestone. Diamond Innovations, a manufacturer of superabrasives used in the material removal industry is located in Worthington, OH, a suburb of Columbus. They employ approximately 400 people who have collectively reached this impressive record seldom accomplished in this industry. The employees of Diamond Innovations sustained an incredible 2,000,000 consecutive working hours without a recorded Lost Time Accident (LTA). LTA (Lost Time Accident) is a work-related injury or illness that results in an employee's inability to perform required work on a subsequent work day or shift. The employees have engaged in safe and cautious work practices on a continuous basis resulting in this honorable achievement. To put this number into perspective, 2,000,000 hours can also be quantified as over two working years. Diamond Innovations has consistently performed better than the U.S. average for LTAs and is a benchmark to other manufacturers in the U.S., especially those in a similar industry.

GLOBAL AEROSPACE COMPOSITES INDUSTRY IS FORECAST TO REACH $4.2 BILLION BY END OF 2018



The demand for composite materials in global aerospace industry has increased double digits in 2011 and 2012 - primarily attributable to the continued ramp up of new and existing large commercial aircraft production and increased build rates across the military and civil rotorcraft market. Commercial aerospace industry continues to utilize a greater proportion of advanced composite materials with each new generation of aircraft. The major commercial aircrafts - A380, B787, B747-8 and A350 ramp up production, the demand for composite materials is expect to grow rapidly during the forecast period. New aerospace programs such as Comac C-919, Bombardier CSeries, Mitsubishi MRJ21, Comac ARJ21, Sukhoi Superjet-100 expect contribute to the growing demand.

FIAT BUYING GM’S STAKE IN DIESEL VENTURE

Fiat SpA is due to become the sole owner of VM Motori, a diesel engine manufacturer, having agreed to buy out its co-owner General Motors Corp. The value of GM’s 50% stake has not been reported. "GM's notification to exercise its put option to sell to Fiat its 50% interest in VM Motori SpA is in line with the contracts Fiat entered into when it acquired a 50% stake in VM in 2010," according to a Fiat statement. VM Motori is headquartered at Cento, Italy, and has been co-owned by Fiat and GM since 2011. VM Motori produces a long list of diesel engines of different styles and configurations, supplying them to numerous automotive OEMs. Among its current customers is Fiat’s Chrysler Corp., which installs a VM Motori-built 3.0-liter V6 diesel engine for the Jeep Grand Cherokee crossover vehicle and Dodge Ram 1500 pickup. Those engines are built from compacted graphite iron engine blocks cast by Tupy SA. Another buyer of VM Motori engines Chevrolet, which offers a 2.0-liter turbo-diesel engine in the Chevy Cruze. The company also produces various marine, industrial, and power-generation engines. "The transaction's satisfactory conclusion is expected before year-end and is conditional upon the requisite regulatory approvals," Fiat stated.

EMO HANNOVER 2013 MORE VISITORS, MORE BUSINESS, MORE INTERNATIONAL DRAWING POWER - GLOBAL ATTENDEES MOTIVATED TO EXPAND AND MODERNIZE THEIR PRODUCTION MACHINERY

Hannover, Germany and Chicago – September 23, 2013 – The leading international trade fair for the machine tool industry – came to a successful close on Saturday 21, September 2014. From September 16 to 21, more than 2,100 exhibitors from 43 different countries were on hand in Hannover to showcase their innovations to industrial users from around the world under, Intelligence in Production, the event’s keynote theme. “This year’s EMO raised the bar in all areas,” remarked EMO General Commissioner Carl Martin Welcker at the end of the fair in Hannover. “With more visitors, more business and more international drawing power, this EMO was more successful than last time around, impressively underscoring its status as the world's premier trade fair for the international metalworking industry,” he added. Over the six days of EMO, the Hannover event attracted a total of just under 145,000 trade visitors from over 100 different nations. EMO Hannover 2013 succeeded again in covering the entire bandwidth of the global machine tool market. Visitors were particularly interested in solutions for boosting energy and resource efficiency, as well as user-friendly equipment and the intelligent integration of machines – in addition to the evergreen themes of cutting manufacturing costs and increasing flexibility. The next EMO will be staged from October 5 to 10, 2015 in Milan, under the motto “Let’s build the future.”

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New Strategies for PcBN and Coatings in Hard Part Turning

By JOHANNES SCHNEIDER
CeramTec GmbH
SPK Cutting Tool Division

New coated cutting materials are opening up new possibilities for hard turning applications with bearing and drive elements, introducing more adaptable cutting data and increased tool life. What's more, a combination of coating technology and the availability of a solid version of inserts is paving the way for new machining strategies which offer significant advantages in terms of reduced processing times, increased productivity and a more efficient overall production process.

Solid versions and a new clamping concept allow for new machining strategies

In comparison to the multi-tipped versions of PCBN inserts, solid versions offer a significantly increased level of process reliability. This safely prevents desoldering of the tip, which is often caused by very long operation times and the resulting high thermal loads. This advantage is of particular relevance when working with larger components, e.g. when preturning large bearing rings. Solid inserts can also be used in a wider range of applications than multi-tipped versions due to their considerably longer cutting edges. With intelligent production process planning, the number of cuts required can be reduced to a minimum, thus significantly reducing the time required to produce the workpieces. This reduces the manufacturing costs for each component.

The small inscribed circles of the inserts, whose dimensions have been optimised for hard turning operations, are yet another advantage of this solution. In combination with the appropriate tooling system, the unique clamping notch creates a force and form locking connection between the insert and the clamp holder, whilst the insert is retracted into the insert seat. This ensures maximum stability, which is essential for successful completion of surface finishing processes such as hard turning. Figure 1 shows this clamping concept.

Figure 2 shows an example in which the combination of the clamping system, solid inserts with small inscribed circle and the selection of a

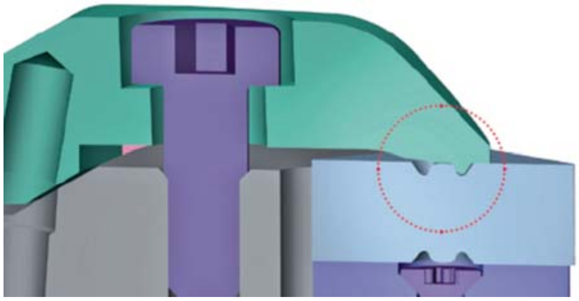

FIGURE 1: Force and form-fitted locking of the clamping with integrated retraction of the solid insert.

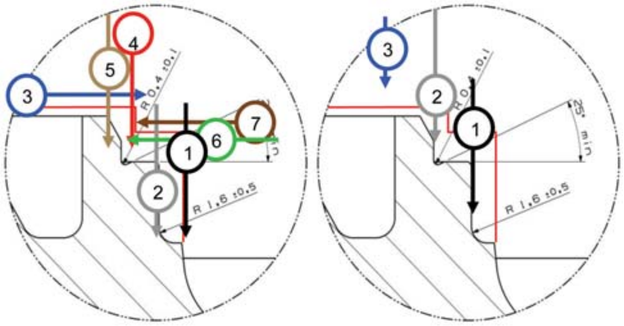

FIGURE 2: Machining the contour of a gear wheel (including hart-to-soft transitions) using solid PcBN inserts (right) in comparison to the solution using conventional multi-PcBN tipped inserts (left)

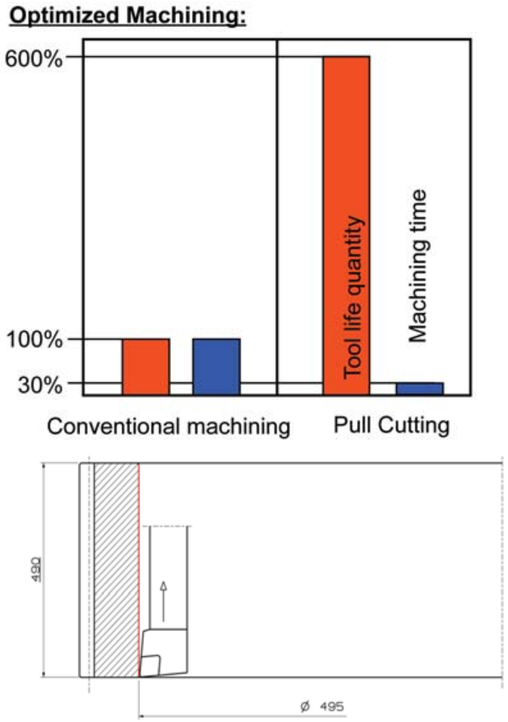

Figure 3: Pull cutting applied by Solid PcBN results in higher tool life and reduced machining time.

new machining strategy leads to considerable savings for the production process.

The contour of a hardened gear wheel is being machined here. Both hard areas, and what are known as hard-to-soft transitions ranging from 30 to 62 HRC, need to be processed here. This, in addition to the relatively large volume to be machined, presents a challenge for the cutting material. To the left, you can see the original machining process required when working with conventional, multi-tipped inserts. A total of seven cuts were needed in order to finish the contour. By using a TNGX110412S-S MDO solid insert and cutting material grade WXM 355 with the new clamping system, it was possible to optimise the overall machining process so that now only a total of three cuts are necessary, reducing the processing time by almost 40%. The solid inserts were used up to a length of four millimetres from the cutting edge.

You can also make use of the longer length of the cutting edge provided by the solid insert style to apply completely new tool paths. By setting smaller attack angles and higher feeds, the required surface quality of the part will be machined within a significantly shorter time compared with the conventional process using PcBN-tipped inserts. Figure 3 shows the machining of a big gear, 500mm in diameter and length. When applying this technology, the tool life increased by factor 6, while at the same time the machining time was reduced by 70%.

Coatings increase the efficiency of hard turning operations

When applied appropriately, multi-layer PVD coatings with a silicon-doped TiN base can produce even better wear characteristics for ultra-hard cutting materials, such as ceramics or PCBN, in hard turning operations. As figure 4 shows, using this kind of coating can also significantly increase the tool life. This illustration compares the wear characteristics of the uncoated cutting material under classic hard turning conditions with the wear characteristics of the coated PCBN cutting material (WXM355).

If the operating limit is defined as a typical width of wear on the cutting edge (width of wear = 0.15 mm), this means that in this case the effective cut length (tool life) achieved through the application of the coating is increased by 170%. An assessment of the condition of the cutting edge also shows an outstanding level of stability, with reduced generation of crater wear (typical with hard turning operations) on the rake face. The remaining crater lip is more stable, preventing breakage of the cutting edge due to a broken crater lip, a common occurrence under hard turning conditions. This means that the necessary surface quality and the dimensional accuracy of the finished hard-turned workpiece can be maintained over a significantly longer period when using coated, ultra-hard cutting materials. The process reliability can be increased a well.

Hard turning operations involve a wide range of machining tasks which in turn lead to various load duty cycles for the cutting material. This is why a whole new range of cutting materials has been created using this coating technology in combination with various ultra-hard substrate materials based either on mixed ceramics or on PcBN. This covers the whole spectrum, all the way from “highly wear-resistant applications with a smooth cut” – WXM 155 (ceramic substrate) to “very tough applications with heavily interrupted cuts” – WXM455 (PcBN substrate). This means that the best type of cutting material is available for each individual hard turning requirement.

The improved wear resistance of the cutting material in coated versions can also be used to increase machining capacity in production systems. Figure 5 shows an example of a wheel hub to be machined in the marked area at a hardness of 58-62 HRC. The machine’s capacity needed to be improved by increasing the processing speed whilst maintaining the prescribed dimensional tolerances as defined in IT6 and a finish quality of $R_z < 4$ µm. Using a WXM255 type TNGX110416S-S MDO coated solid insert allowed the cutting speed to be increased to v_c = 260 m/min with unchanged values of $a_p \times f$ = 0.2 mm x 0.16 mm. This reduced the machining time required for the part by 22% compared to the initial conditions.

The tool system and coated solid inserts described also offer benefits in the area of ball and roller bearing machining. When preturning a bearing ring profile with a smooth cut in the hardness range of 59 HRC or lower in the specified hard-to-soft transition zones, a surface quality of $R_a < 0.6$ µm and a high level of process reliability are required (see figure 6). Using the specific tooling system as described above and a RNGX060400S-S MDO type solid inserts in the ceramic-based cutting material WXM155 resulted in a six times higher tool life

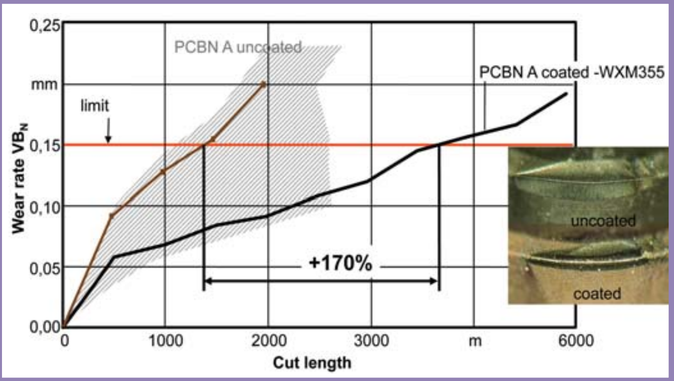

FIGURE 4: Impact of the coating on wear characteristics and the condition of the cutting edges for hard turning operations (WXM355) in comparison to uncoated versions of the same PcBN substrate.

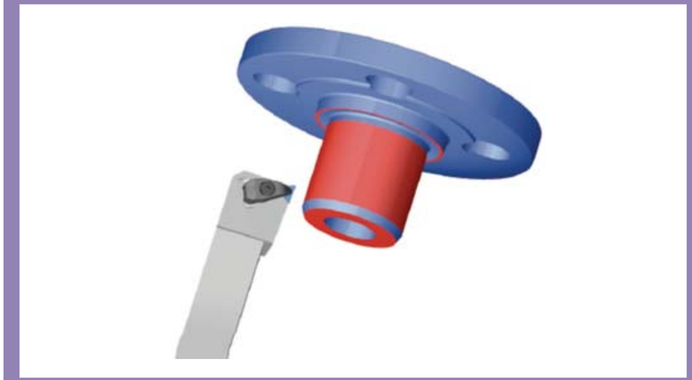

FIGURE 5: Longitudinal turning and facing of a wheel hub at 58-62 HRC with increased cutting speed.

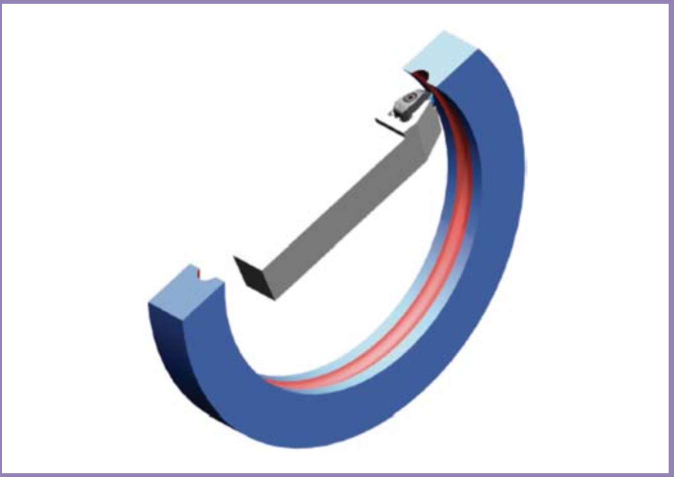

FIGURE 6: Profiling - semi-finishing a bearing ring, 59 HRC with a hard-to-soft transition.

The improved wear resistance of the cutting material in coated versions can also be used to increase machining capacity in production systems.

quantity as compared to the results from the whisker reinforced ceramics previously used (at a cutting speed of v_c = 210 m/min, cutting depth of a_p = 0.6 mm and a feed of f = 0.15 mm).

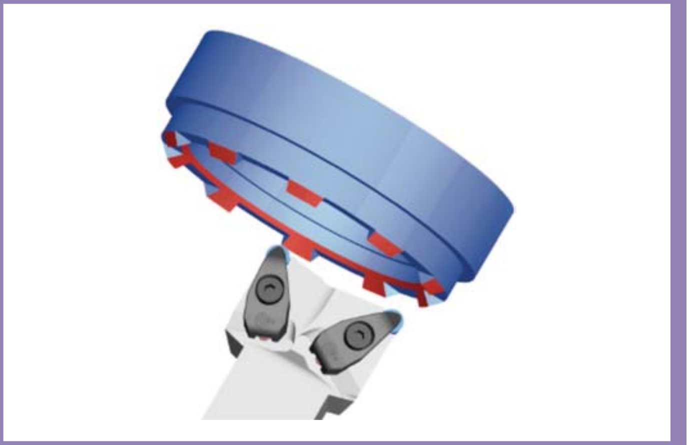

FIGURE 7: Turning the contour on a shaft, 58-62 HRC, with heavily interrupted cuts.

Using suitable tools and cutting materials can also ensure production reliability when processing heavily interrupted cuts in hard turning operations. The example in figure 7 depicts the machining of a special contour of output shaft made from case hardened steel with a hardness of 58 to 62 HRC. A special tool can be used to finish both the outer and the inner contours in one single processing sequence. The cutting speed is v_c = 130 m/min, the feed is f = 0.10 mm and the cutting depth is a_p = 0.8 mm. The extremely tough WXM455 cutting material enabled the cutting edge to withstand the high strain of heavily interrupted cutting with high process reliability. At the same time, the tool life per cutting edge of this coated grade was almost 2.5 times longer than the results achieved using conventional PCBN cutting materials.

CONCLUSION

The combination of solid inserts and highly stable clamping systems made it possible to apply new machining strategies when manufacturing hardened workpieces. This reduces the cycle times considerably when achieving high tool life, which in turn offers economic advantages. If these kinds of machining strategies have already been taken into account in the design process, shortening the process chain and increasing production capacities also reduces costs.

New coatings are also able to achieve higher cutting speeds for hard turning operations. The wear resistance of the cutting material is even more impressive when compared to the uncoated variants and the improved resistance to crumbling or breakage of the edge means that the production reliability is also significantly enhanced again here.

In addition to classic hard turning components, particular advantages are offered for turning hardened large components, for cases of heavily interrupted cuts and for hard to soft transitions on components. Coated cutting materials for solids, based on ceramics or PCBN, along with the corresponding tool systems offer outstandingly efficient, more reliable machining processes, particularly for workpieces with these kinds of characteristics. ●

Hard Turning – TYPICAL WORKPIECES

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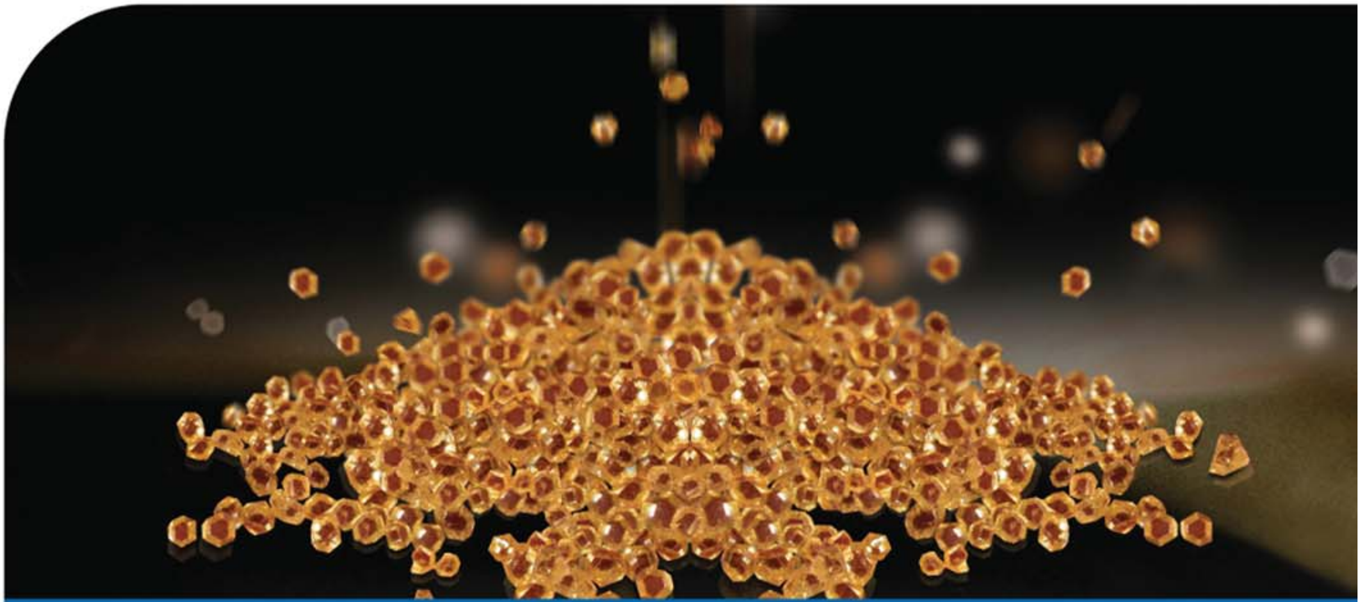

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High Efficiency in Machining Carbon Fiber Composites & Metal Stacks for Aerospace Application

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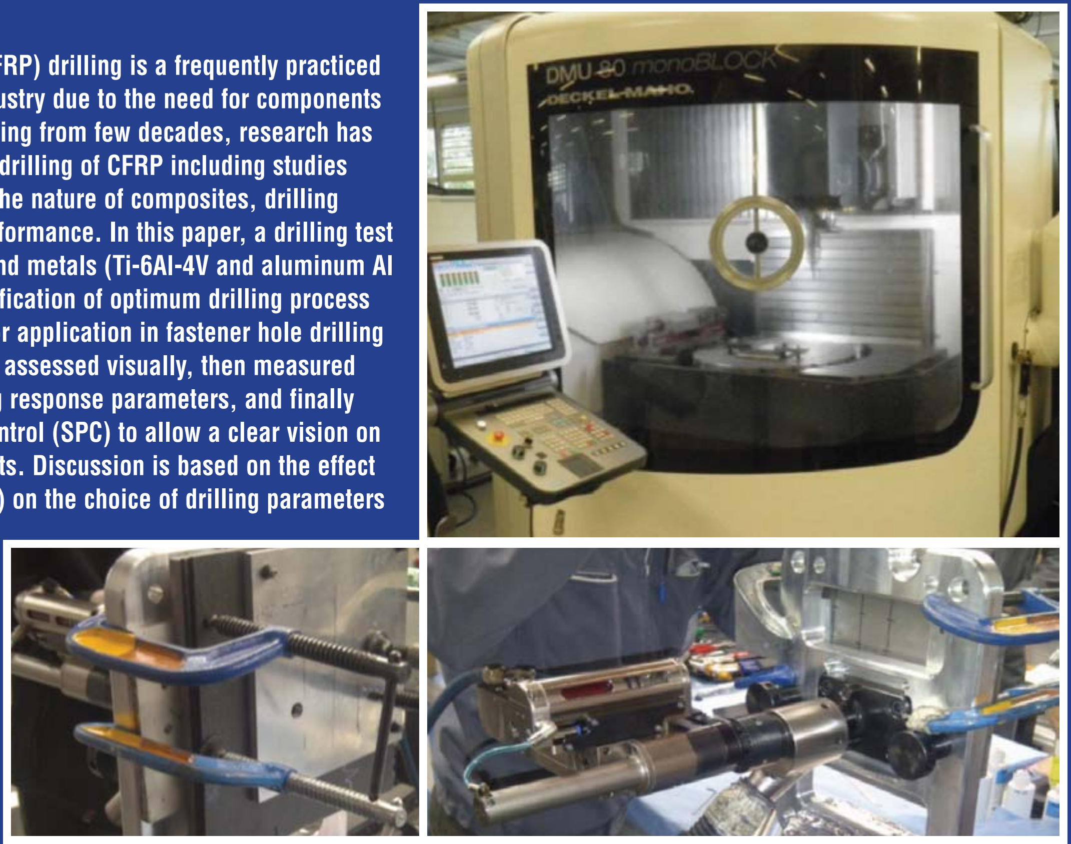
INTRODUCTION

Carbon Fiber Reinforced Plastics (CFRP) has been applied to primary structure of large commercial aircraft, as a means of enhancing overall performance. These aircraft are being developed and produced in a unique way where major OEM's are acting as System Integrators and using Risk Sharing Partners to develop the majority of the principal processes and components. To support this new business and technological model it is necessary that the System Integrator have sufficient knowledge and tools to support the development of the whole manufacturing processes. Of particular interest is the machining of CFRP parts, as they are complex and expensive items, thus offering large opportunities for optimization, in particular when they are stacked to metal parts such as titanium.

ABSTRACT

Carbon Fiber Reinforced Plastics (CFRP) drilling is a frequently practiced machining process in aerospace industry due to the need for components assembly in aircraft structures. Starting from few decades, research has been conducted to achieve effective drilling of CFRP including studies related to different aspects such as the nature of composites, drilling parameters and hole quality and performance. In this paper, a drilling test program was undertaken for CFRP and metals (Ti-6Al-4V and aluminum Al 7074) stack, with included the identification of optimum drilling process parameters and tooling conditions for application in fastener hole drilling and assembly. Hole quality was first assessed visually, then measured using both geometric and processing response parameters, and finally integrated in a statistical process control (SPC) to allow a clear vision on short and long term production results. Discussion is based on the effect of the stack components (CFRP/Ti/Al) on the choice of drilling parameters (feed rate and cutting speed) and consequently the quality of the hole based on drilling parameters, surface quality, chip evacuation, entry and exit edge integrity. Finally, an optimal operating parameters window for CFRP/Ti/Al stack will be suggested for a secure machining process.



Stacking composites and metals such as titanium and aluminum is not new. The materials combination has been around for at least 20 years replacing titanium or aluminum assemblies in high-stress wing areas, such as where the wings join the fuselage. The material theoretically calls for two different tools, one that fits the attributes of a composite and a different one that fits the attributes of the titanium. But only one type of tool can be used in each pass through the hole.

Composites are extremely abrasive, making coated drills the preferred choice. However, PCD as an example of coating doesn't last long when drilling titanium, which creates a great deal of heat. On the other hand, what works in titanium, such as carbide, doesn't last long in composites. Machinists generally end up selecting carbide drills, as wearing out PCD drills in titanium is expensive.

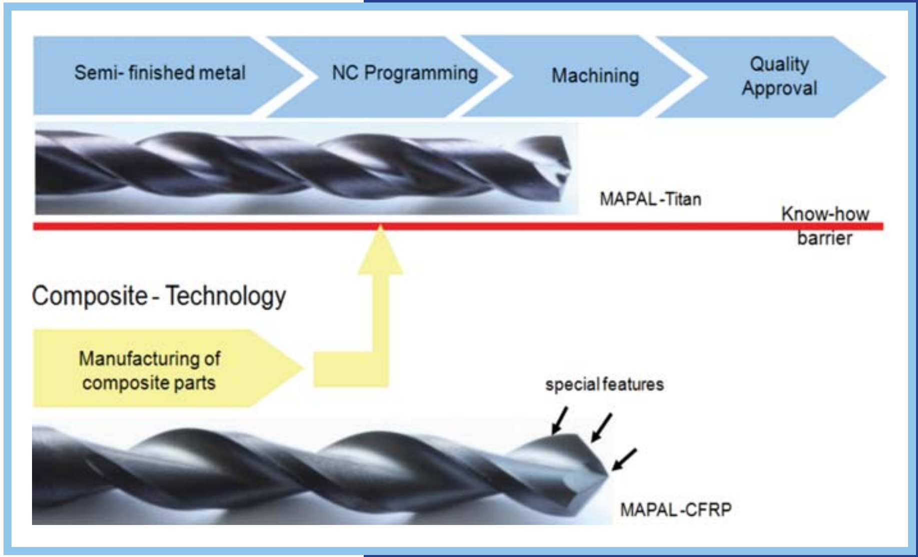


Figure 1: **Process Know-How in Machining Metal vs. Carbon Fibre Reinforced Composites**

The main objective of the present study is the development of a CFRP/Metal drilling tools getting the geometry aspect as a primary focus to achieve drilled holes quality as required by major aerospace drilling specifications.

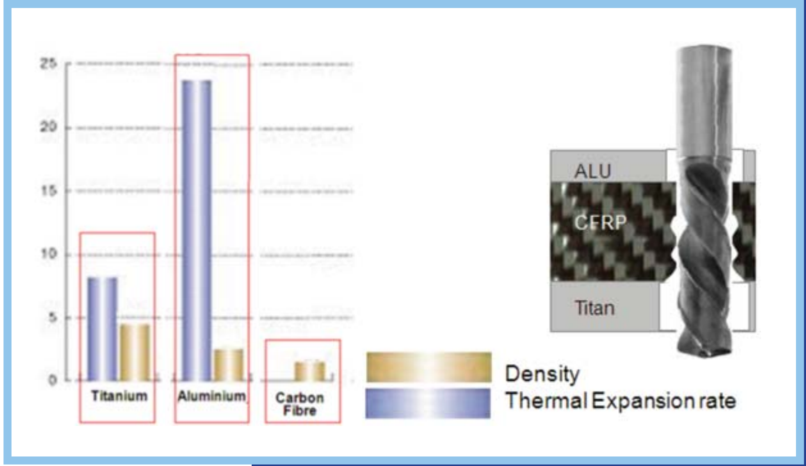


Figure 2: **Effect of Stacked Material Properties on Final Drilled Hole Diameter**

DRILLING CFRP / Metal STACKS

Since automated Aerospace assembly sites are looking for one shot drilling CFRP/Metal stacks without any disassembly before riveting the structures, the drilling process development become much aggressive in term of cutter performance giving the highest number of holes according to final product specifications (PS). Therefore, final hole for all substrates (CFRP and metals) has to be achieved according to diameter, entry & exit burr, delaminations, surface roughness, countersink concentricity,.. in one shot which means one tool in minimum time.

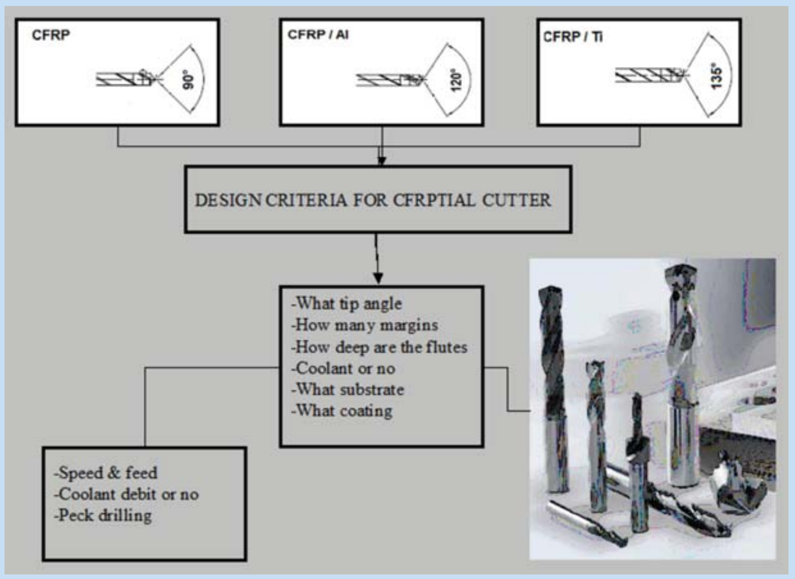


Figure 3: **Tool Geometry Selection Process**

Developing a cutter at MAPAL passes through identification and deep analysis of all physical aspects during the drilling of stack components separately then joined together. A first study conducted on barrier limit between drilling CFRP and metals as illustrated in figure 1 reveals that metal drilling as known since many decades is based on pure continuous mechanics, which is not the case when drilling CFRP. A cutter drilling very tough carbon fibre reinforced fully cured epoxy resin is working in most of the drilling process under fracture mechanics law. The fibres have to be aggressively broken but care must be taken to get a smooth final surface finish, which

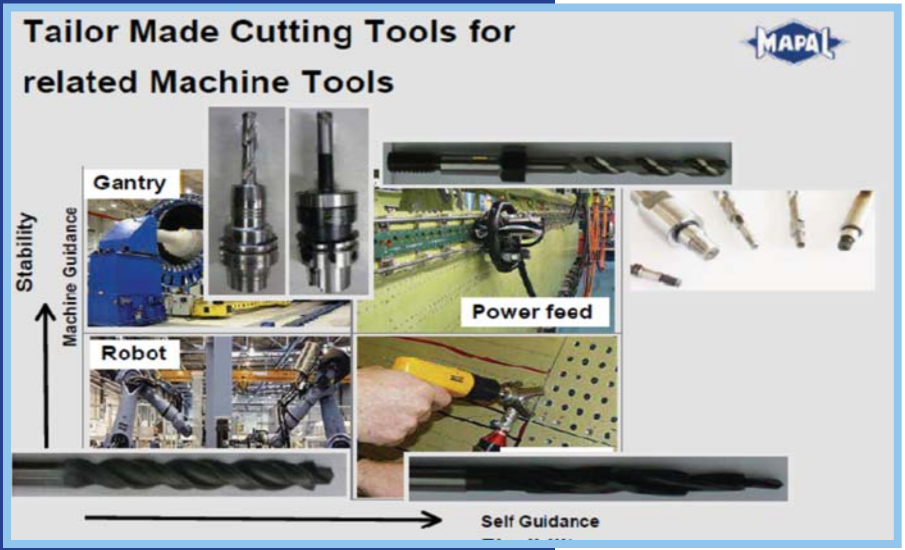


Figure 4: **Related Machines to Cutter Geometry**

means, a well established control of machining parameters as spindle speed and feed. At this point, MAPAL cutter's geometry is developed taking the fibre type and properties as primary input. As an example, a multidirectional CFRP layup configuration does not have to be treated as a same case like a unidirectional fibre layup composites. Difference can be explained by the fact that, unidirectional layup has no support of fibre between each other like a woven or stitched and this aspect results in non cut fibres and delaminations.

On a second hand, stacking CFRP with metal to get a one shot drilling deals with material substrate behaviour and response to drilling effort. CFRP material is well known as a very stiff with special thermal expansion behaviour. Most of the studies revealed that drilling a CFRP substrate always bring the hole near the cutter diameter when the process is done properly. This is a result of a hole contraction against the cutter during the machining process. However, the same studies revealed also that metal drilling when conducted on titanium or aluminium leads to hole diameter larger that what is expected to be from the cutter diameter. Again, the phenomenon is purely physical when we look to thermal expansion and densities of these materials as figure 2 shows.

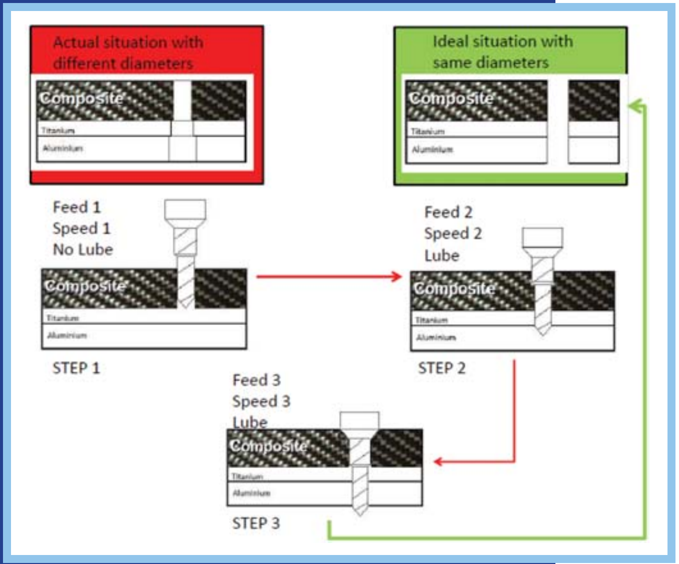


Figure 5: **Getting to the Same Diameter in Stack Drilling**

For static and fatigue issues of the aircrafts structures, specifications for stack drilling require more and more tight tolerances for hole diameters and assembly purpose. H8 or H9 tolerances are well known to be hard to achieve in composite materials drilling and therefore, achieving H8 or H9 tolerance in a stack drilling was the mostly studied aspect of major Aircrafts builders and cutters suppliers. Two shots drilling and reaming process was the adopted solution to solve the tolerances issue for the hole diameter of the whole CFRP/Metal stack, however, the process time for machine setup and drilling as well as quantity of tool management become the new issue.

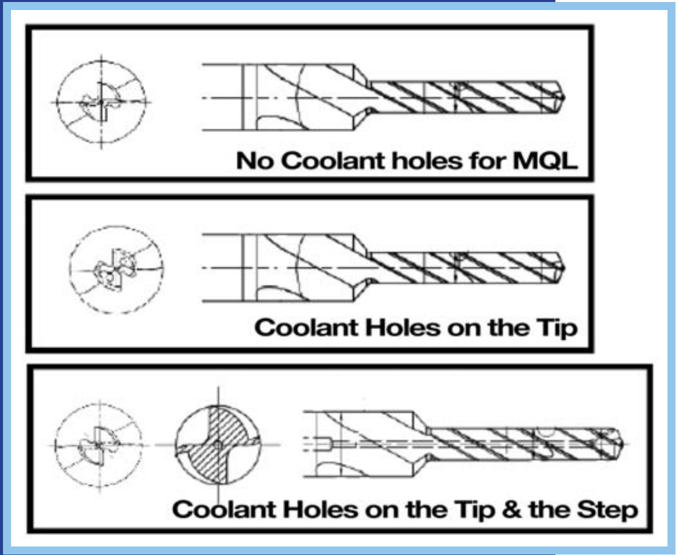


Figure 5: **Drill Options**

MAPAL engineering and design people focused on the previous described issue and developed a new technology cutter to reach the hole specifications. Starting for the fundamentals stating that CFRP, titanium and aluminium have to be drilled with different feed and speed, the geometry of the cutter has to be adapted to the change of cutting parameters and also the change of drilled material. The substrate type (Solid carbide) has to chosen for more stiffness for CFRP machining and fine grain for metal especially titanium drilling. Cutter geometry including tip angle, number of margins, flute depth are also designed to overcome the difference in drilled material properties (CFRP, Ti, Al). Figure 3 shows the general procedure for tool selection.

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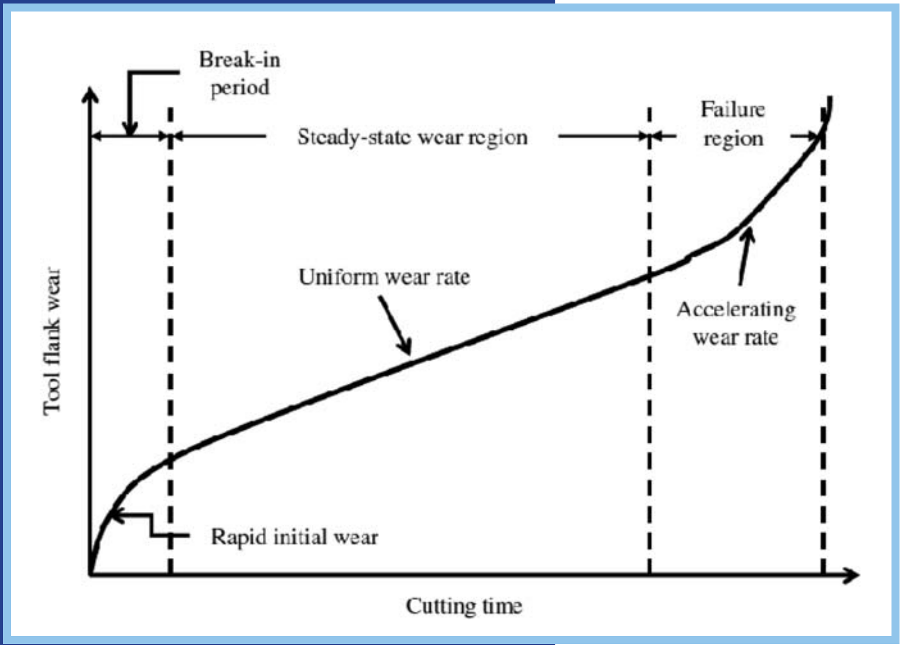

Figure 6: **Tool Wear During Drilling Process (Vaughn [6])**

In addition to the drill design, the drilling process parameters definition helps the designers to decide on how the tool geometry has to be adapted to overcome multistack materials drilling issues in term of process flexibility and stiffness as can be seen in figure 4. Any process showed in the figure 4 has to overcome the abrasive character of the CFRP, the heat release issue from the titanium and the buildup and jamming issue from the aluminium. Therefore, developing the best holemaking process for the stacked materials combined with hole specifications and tool life requirement (cost/hole) become the highest concern of today's cutting tool suppliers as well as aerospace assembly OEM's.

DRILL DESIGN

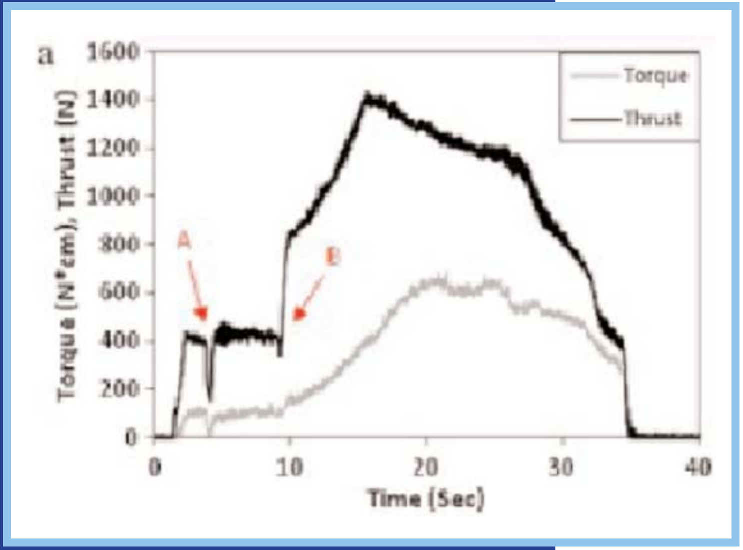

Figure 7: **Thrust and Torque During CFRP/Ti Drilling Process [7]**

Quality issues in drilling CFRP/Metal stacks relates mainly to diameter changes from CFRP to titanium and then aluminium, fraying and delamination in the CFRP as well as entry and exit burr in both metals. The order of materials in the stack and even whether the holes will be drilled using a CNC stiff machine or by flexible hand motor all make a difference in the needed tools and machining parameters. From that point of view, MAPAL has a common rule to work in close collaboration with Aerospace OEM's customers in designing and testing the potential drill geometries for the right application.

For a chosen holemaking process, the effective drill design should include minimally the following aspects:

- Stack composition (CFRP/Ti/Al)
- Stack thickness
- Type of CFRP (carbon fiber & resin)
- Type of titanium (most used Ti6Al4V)
- Type of aluminium (Soft 2024 to hard 7475)
- Need to coolant for the tool (No Coolant, MQL, external lube, …)
- Process speeds and feeds
- Peck drilling or uniform feed

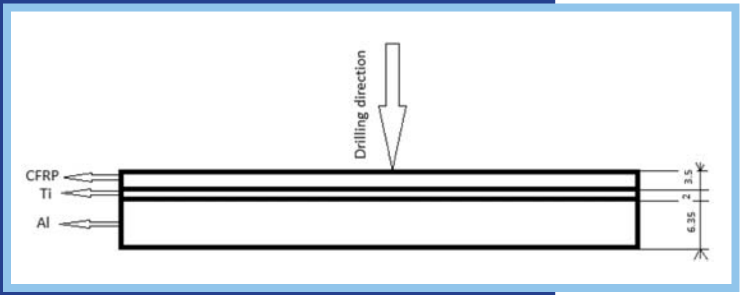

Figure 8: **Stack-up and Drilling Configuration**

For the first issue in stack drilling, MAPAL engineering team focus on the physical aspects causing hole diameter difference in each material (CFRP, Ti and Al). As stated in many studies [1, 2 and 3], the type of drilling machine, the nature of the stacked materials, the feed rate as well as spindle speed, all have a strong influence on the difference in diameter. For the same point of view, Carvajal and al [3] found that cutting speed displays a smaller influence than the rest of the factors listed before.

From the process illustrated in figure 2, the development was firstly concentrated on the geometry of the tool itself in accordance with all materials and machining parameters listed before. Therefore, the hole diameter for all stacked materials was simply adjusted by modifying the concept from drilling to drilling and reaming where it is exactly needed. Most stacked materials in aircraft industries are CFRP/Al or CFRP/Ti or also CFRP/Ti/AL, then fine reaming of these stacked materials where it is needed would solve the problem without the need to a post process or secondary operation of reaming. The reaming technology added to MAPAL drills named Micro Reamer© was then tested and analyzed in the next sections.

Micro Reamer© technology is an added machining phase to the well-known three standard phases when drilling a hole: first is the start and centering phase, second is the full drilling phase and finally the break through phase [4]. MAPAL drill geometry is designed firstly with special geometry on the tip and flute depth to achieve metal (Al or Ti) chips evacuation without affecting the CFRP surface roughness. Once it comes to the end of the process, the Micro Reamer© enables the drill to achieve superior hole quality without any surface scratches leading to a well desired surface finish and the right hole diameter as per Aerospace specifications as illustrated in figure 5.

Lubrication method and parameters during drilling process are directly related to the cutting speed and feed which are the major factors affecting the temperature variation during stack drilling. This corresponds with the high cutting energy, deformation strain rate as well as the heat flux [5]. Furthermore, drilling at high feed rate increases the friction and stresses, thus increasing the cutting temperature which results in hole diameter mismatch between CFRP, Al and Ti based on deformation due to temperature increase or thermal expansion. To overcome this problem in Aerospace stack drilling

Drill Number	***Material***	***Spindle Speed** (RPM)*	***Spindle Feed** (IPM)*	***Peck** (INCH)*	***Coolant***
30358647	CFRP	9000	13	No	No
	Ti	1000	2.5	0.010	Mist
	Al	9000	25	0.010	Mist
30416600	CFRP	9000	13	No	MQL
	Ti	1000	2.5	0.010	MQL
	Al	9000	25	0.010	MQL
30473441	CFRP	6000	13	No	MQL
	Ti	1000	2.5	0.040	MQL
	Al	9000	25	0.040	MQL

Table 1: **Machining Parameters**

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application, there are three different cooling methods incorporated in the drill geometry as shown in figure 6. A non-coolant holes drill dedicated to a dry drilling or a flood drilling, MQL on the tip of tool and MQL on a well location position on the flute that gives a dry step drilling helping the cutting process in term of CFRP dust evacuation of cooling the metal chips down especially when peck drilling is applied.

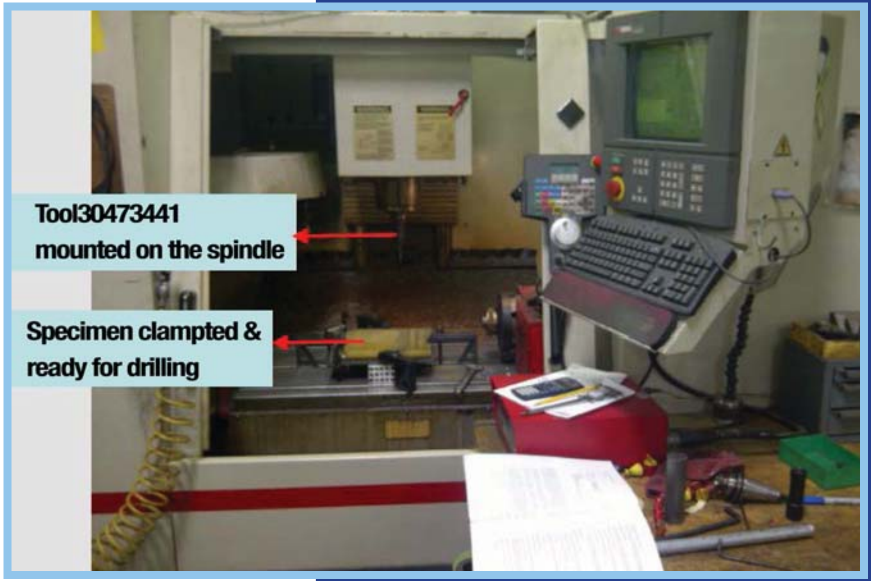

Figure 9: **End Effector Drilling and Riveting Process [9]**

TOOL WEAR

One of the key challenges in Aerospace stacks drilling is composites and metal removal rates with reasonable tool life. Recent advances at MAPAL development center in tooling technology has made the goal of high drilling with longer tool life possible. As a result, MAPAL offers now high-design quality cutters (drills) for stack machining with shorter cycle times, increased tool life, and higher shop productivity.

As for damage propagation in a metal or composite structure, tool wear progression follow the rule of rapid initial wear followed by uniform wear with the most longer time and finishing by failure region as shown and studied by Vaughn [6]. The first step of tool wear called break-in period is where the tool is adapting itself to the machining parameters and materials. This step can be for few first drilled holes less than 10 for most cases. The second step, a well-established and uniform wear can occur and is dependant to many parameters like cutting feed and speed, materials type and thickness and lubrication. This step is also defining the capability of the drilling process as per statical analysis process (Cp and Cpk). The last period dictates the time or maximum number of holes that the tool can achieve and lead also to the productivity cost or cost per hole.

Drilling CFRP-Al-Ti stacks with uncoated solid carbide cutters, leads to the following tool wear characteristics:

1 – Abrasion by the carbon fiber

2 - Adhesion of metal covering the entire cutting edges which constitute one major tool wear factor. PCD drills on the other hand, showed less titanium adhesion, but had a significant amount of cutting edge chipping [7];

3 – Higher torque and thrust are observed when the drill penetrates the metal stack after finishing the composite hole as per figure 7. Therefore, the high load on the cutting edges with uniform feed on

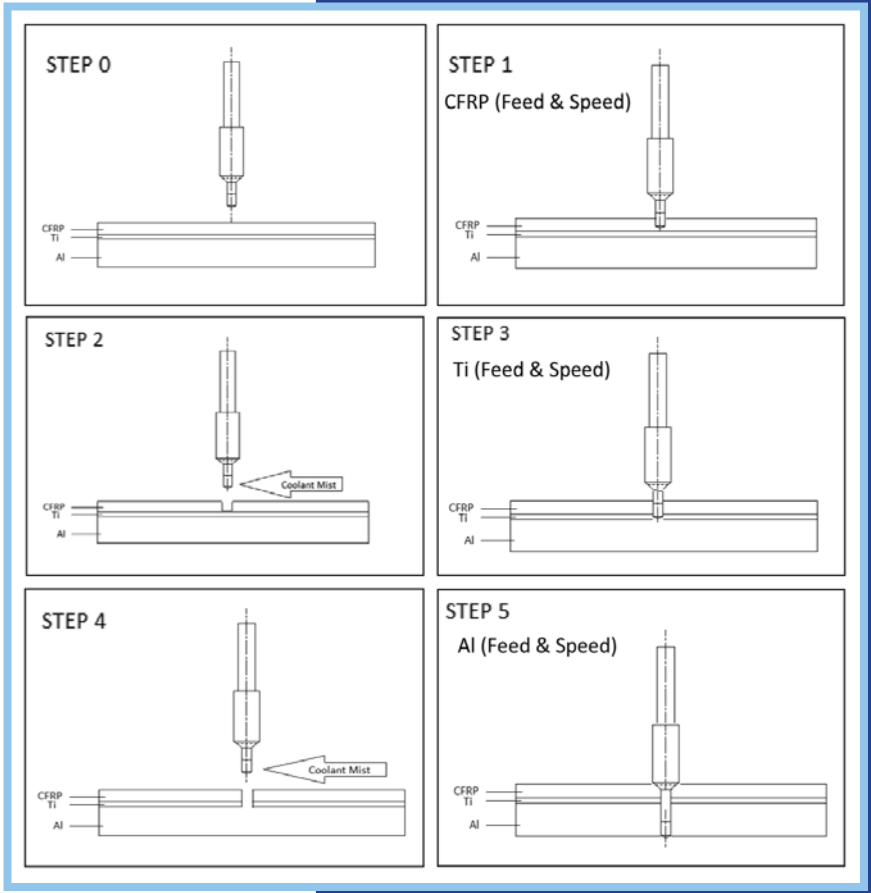

Figure 10: **Drilling Step for External Mist Coolant**

the tool working under continuous mechanics to uniformly cut the metal bring the material to higher temperature reaching for most cases plasticity limit. This phenomenon dictates the rate of material built-Up on the tool surface itself. J.S. Colton [8] studied the tool wear in term of chip formation in metal, cutting fluids for lubrication as well as vibration (pecking). One highlighted point in this study was the difference between the types of chips formed during metal cutting. From continuous chips process to discontinuous ones process, the Built-Up process decreases tremendously and leads to well controlled hole diameter and tool life for phase 2 in the figure 6.

CASE STUDY

The stack-up for machining tests was composed from a quasi-isotropic laminate layed up and cured in a controlled aeronautical environment using pre-impregnated technology, a titanium Ti6Al4V and aluminum 7000 series plates of 12 x 24 inches. The stack arrangement, material's thickness and the drilling direction are showed in figure 7. For testing purpose, no sealant was used between the composite and Ti or Ti and Al plates due to disassembly request for interlayer delamination and burr evaluation.

The drilling tests were carried out on a Cincinnati machining center (figure 9) using different drill configurations as listed in table 1. All cutting parameters in table 1 are results from an optimization project run at MAPAL R&D Lab focusing on hole quality. Also, all drills are solid carbide with CVD diamond coating with the following descriptions: Tool number 30358647 is a 3 margin completely coated and without MQL holes. Tool number 30316600 is a 3 margin completely coated with MQL on it's first step. Tool number 30473441 is a 3 margin without coating on the first step and full coating on the micro reamer portion and with MQL. Therefore, the differences for all these drills are in the MQL and the coating strategies as per figure 5.

Drilling process with cutter 30358647 involves 6 steps including retracts after each material drilling to let cutter lubrication for metal hole making. Figure 10 is a step by step description of the whole process used with that tool. The two other drills where running under one shot drilling process since MQL is also running along the whole drilling for all stacked materials.

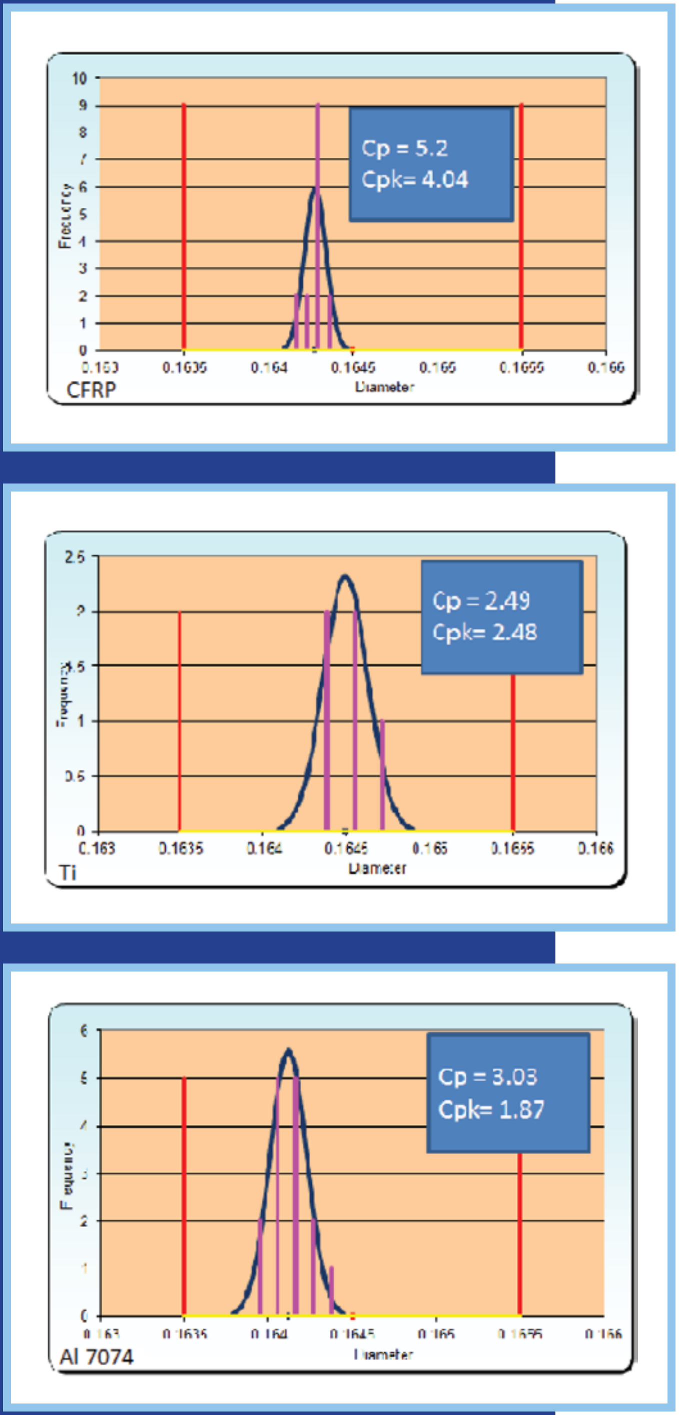

Figure 11: **SPC Process for Holes Drilled with 30358647**

STATISTICAL PROCESS CONTROL (SPC)

For the present study, the purpose of statistical quality control is to ensure, in a cost efficient manner, that the product studied meet the aerospace specifications. In aerospace industry shop floors, inspecting every hole is costly and inefficient, but the consequences of getting non conform drilled holes can be significant in terms of customer dissatisfaction. Statistical Quality Control is the process of inspecting enough product from given lots to probabilistically ensure a specified quality level.

Hole quality is inspected in term of diameter, interlayer and exit burr, surface roughness, holes concentricity and countersink positioning. For the case of the present study, we'll limit the SPC process to hole diameter factor since it is the most and predominant controlled item during stack drilling. Thus it is important to evaluate the process capability of drilling on the stacked materials. It will thereby reveal the spectrum of deviation to be accepted from the view point of process capability for a chosen range of material, drill diameter, speed and feed rate combinations.

Results from drilling with tool number 30358647 are showed in figure 11 from which, we can see on one side the good process accuracy limited by the lower and upper spec limits for hole diameter 5/32''. On a second side, we can observe a non centered Aluminum curve getting a tendency to the lower limit. This aspect can be explained by feed and speed optimization when it comes time for transition from Ti drilling to Aluminum. In that case, it can be difficult to really center the curve since the drilling process of the portion Ti/Al in the stacked materials is more controlled by the Ti than Al in term of speed and feed parameters. Therefore, modifying the speed and feed when the tip of the drill goes inside the Al can create a considerable defect at the end of Ti hole. On other side, if the drill remain running at the Ti speed and feed, creates an Al hole diameter which tends to go outside the desired limits.

Figure 12 is the result of statistical control for holes drilled using tool number 30416600. The CFRP, titanium as well as aluminium drilling process is shown to be under control of hole diameter using tool 30416600 with a stable Cpk for all stacked materials a well centered curve between the lower and upper spec limits. This better process control is due to the fact that using MQL holes behind the tip of the tool with the applied peck drilling leads to a better control of chips temperature by continuously cooling them while extracting through the drill flutes. Comparing this process to the one found (figure 13) with drill number 30473441, we can clearly observe the effect of MQL holes positioning especially for stackups including Ti and Aluminum.

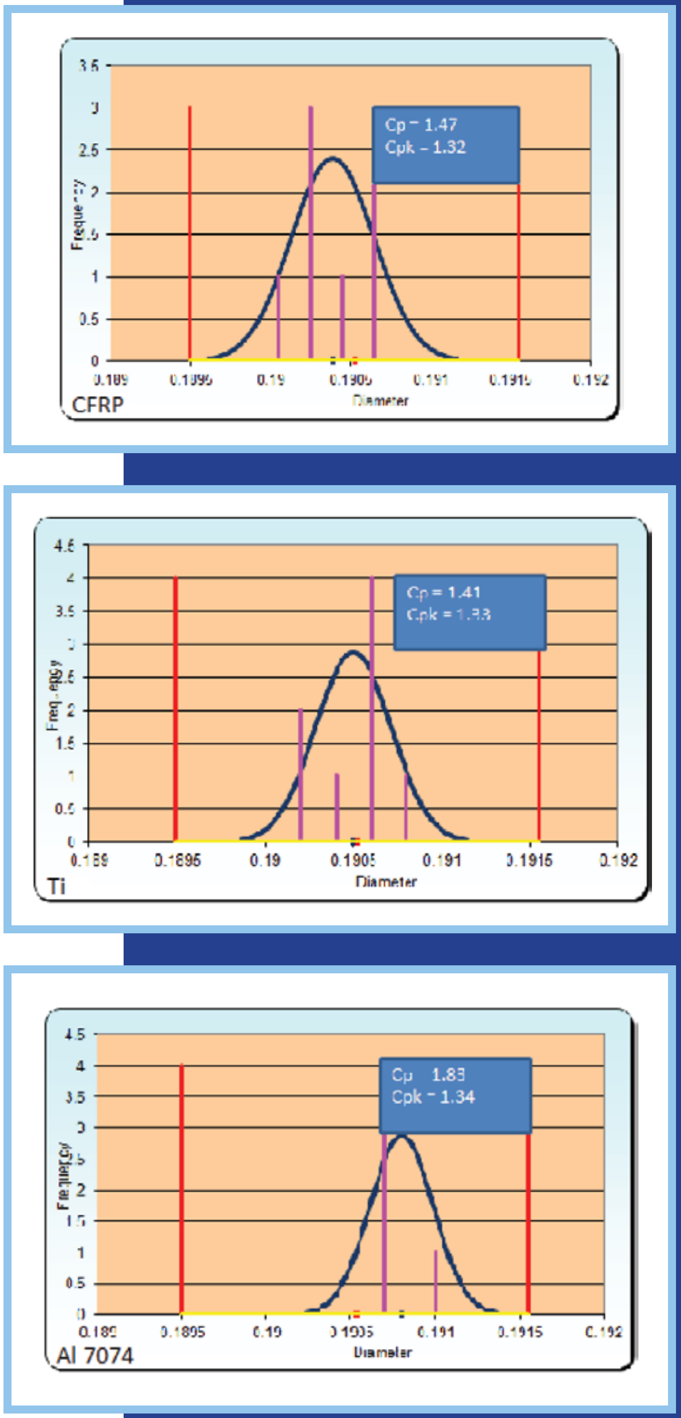

Figure 12: **SPC Process for Holes Drilled with 30416600**

CONCLUSION

Understanding the physical process while drilling CFRP/Ti/Al stacks for aerospace applications is the success key for the optimum drill geometry design. Heat generation when drilling metals like titanium and aluminium causes diameter changes in both materials which are mainly affected by the rate of heat generation which in turn is affected by cutting speed and feed. In the present study, the heat generation issue was overcome using optimum drill design with a well-positioned MQL holes. In fact, the heat generation from metallic materials is transferred through the chips to whole drilled hole. Therefore, cooling down the chips and guiding them inside the flutes at lower temperature leads to an optimum hole diameter with respect to manufacturing specifications. ■

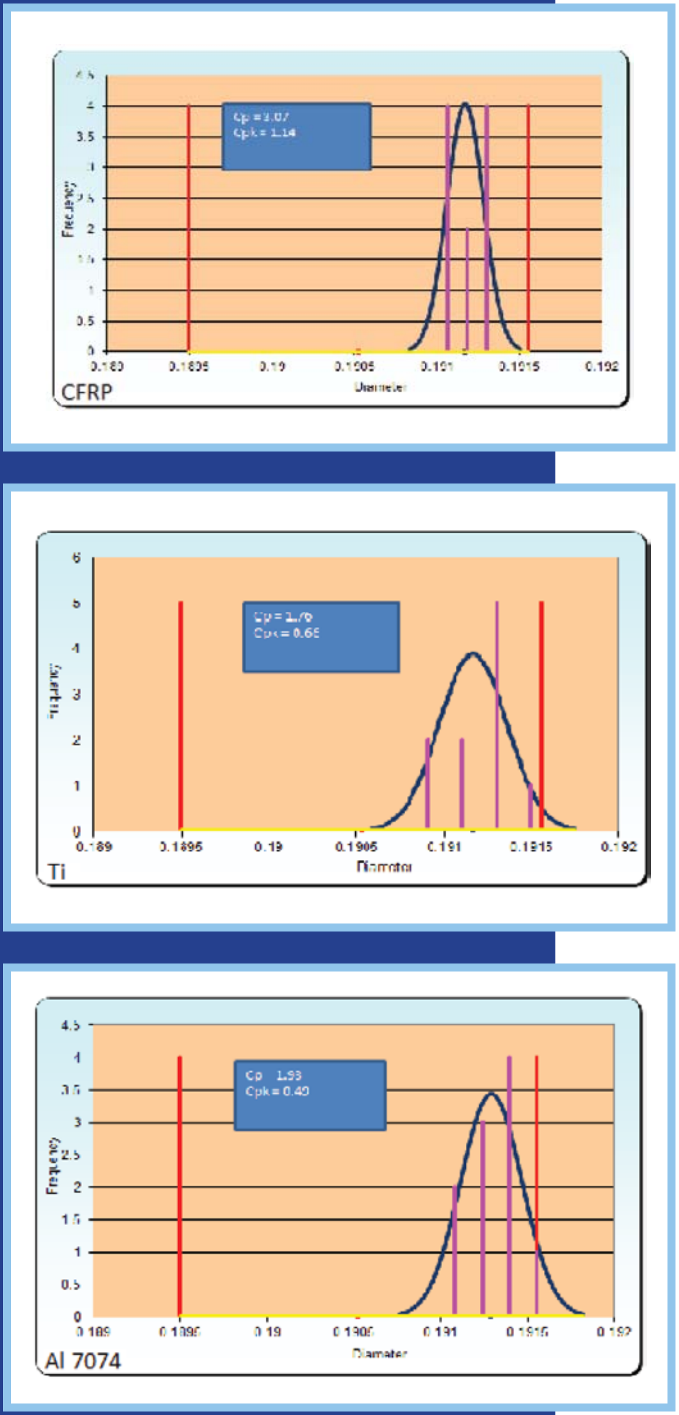

Figure 13: **SPC Process for Holes Drilled with 30473441**

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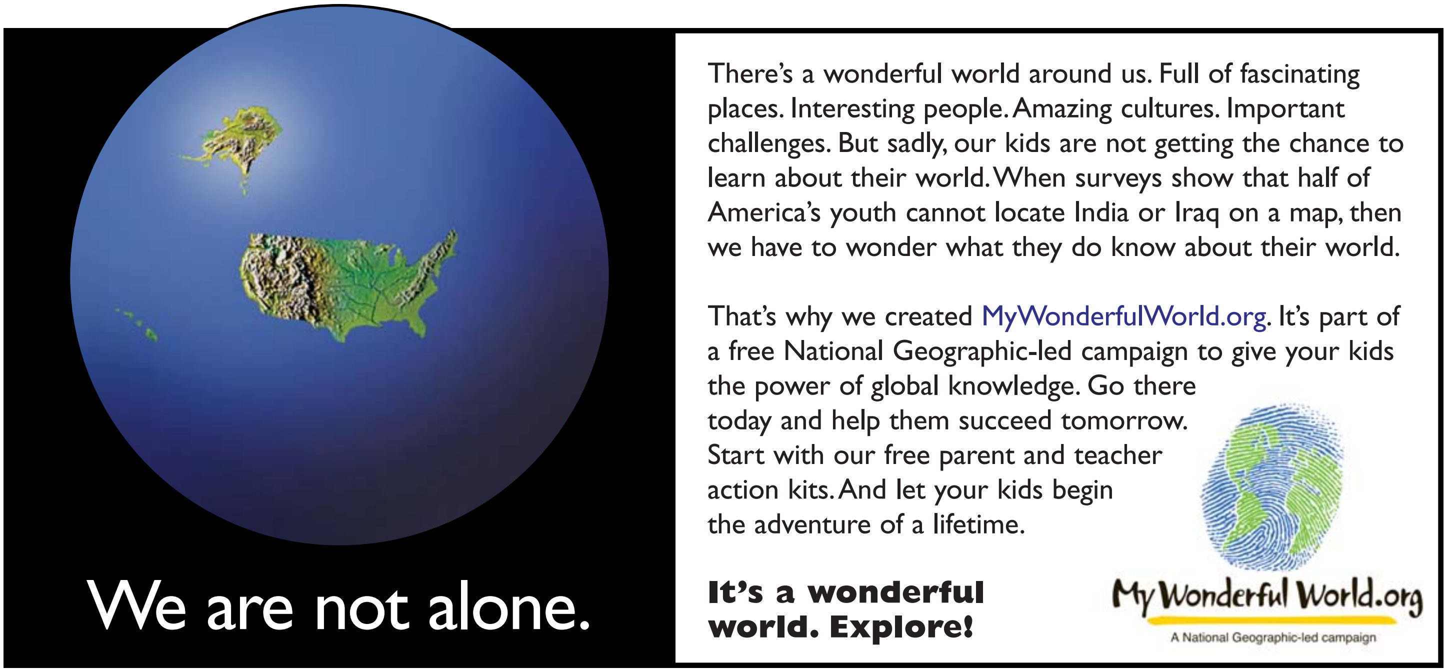
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